ELECTRON IRRADIATION OF TANDEM JUNCTION

SOLAR CELLS*

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SUMMARY

The electrical behavior of 100 micron thick tandem junction solar cells manufactured by Texas Instruments has been studied as a function of 1 MeV electron fluence, photon irradiation, and 60°C annealing. These cells are found to degrade rapidly with radiation, the most serious loss occurring in the blue end of the cell's spectral response. No photon degradation was found to occur, but the cells did anneal a small amount at 60°C.

INTRODUCTION

The Texas Instrument tandem junction solar cell (ref. 1) is constructed with a junction on the front surface and a junction on the rear surface in an n^+pn^+ configuration. The front surface, usually textured, has no grid lines or contacts of any kind. An n^+ layer is diffused in a fingerlike pattern on the rear surface which leaves both n^+ and p material exposed for purposes of contact deposition. This construction, with contacts only on the rear surfaces permits simplified cell interconnection during panel construction. An additional advantage is that these cells have worked quite well at thicknesses down to 100 microns. Their performance after 1 MeV electron irradiation, annealing, and photon exposure is the subject of this paper.

We have irradiated and measured three TI tandem junction cells using the JPL Dynamitron as a source of 1 MeV electrons. I-V curves and spectral response measurements were made as a function of fluence, photon irradiation and 60°C anneal. All three cells had textured, contactless front surfaces. They were furnished mounted on thin ceramic substrates. Cell 20-2 was made of 3 ohm-cm CZ silicon, 100 microns thick, area 4 cm^2, and cells 34-1 and 38-1 were 6 ohm-cm CZ silicon, 110 microns thick, area 4 cm^2. P contacts were Al-Ti-Pd-Ag and n contacts were Ti-Pd-Ag. All junction depths front and back were reported to be approximately 0.25 to 0.3 microns deep.

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IRRADIATION

The results of the irradiated data are plotted in figures 1 to 3, showing I_{sc}, V_{oc} and P_{max} vs. 1 MeV electron fluence. All measurements are AMO, 28°C, made with an Aerospace Controls Model 302 filtered xenon simulator. The cells were annealed for 16 hours at 60°C after the cumulative fluence reached 2×10^{14} e/cm^2. The values after annealing are used in the plots. The changes in I_{sc} and P_{max} are dramatic. After 10^{15} e/cm^2, cells which began with efficiencies of 11.84%, 8.96%, and 13.47% have been reduced to 0.67%, 1.99%, and 0.81%, respectively. Cell 20-2 made of 3 ohm-cm material is seen to be the most vulnerable. It dropped to an efficiency of 1.69% after 2×10^{13} e/cm^2, then decreased in output slowly with fluence. The two 6 ohm-cm cells did not decrease as rapidly until exposed to somewhat greater fluences, but when they fell their output coincided with that of the 3 ohm-cm cell. The V_{oc} behavior of all three cells has roughly the same trend as shown by Figure 2, but the undulations in the cell 38-1 curve could possibly be due to a thermal contact problem involving the cell/ceramic structure.

ANNEALING AND PHOTON EFFECTS

All three cells were annealed at 60°C after higher fluence exposures. All cells showed positive annealing after this treatment in all cases, with the 6 ohm-cm cells showing a greater effect than the 3 ohm-cm cell (this duplicates the behavior of conventional structure cells). The annealed 6 ohm-cm cells showed improvements in I_{sc} of between 7 and 27%, in P_{max} between 9 and 37% and in V_{oc} between 0.7 and 4.8%. The annealing in the 3 ohm-cm cell was between 1.5 to 5% in I_{sc}, 5 to 17% in P_{max} and 1.2 to 2.5% in V_{oc}.

Cell 20-2 was subjected to a 3-day exposure to tungsten light following the 10^{15} e/cm^2 fluence and to a 35 hour light exposure following the 10^{16} e/cm^2 fluence. No reverse annealing was observed, but there was evidence of damage recovery of roughly 2% in I_{sc} and V_{oc} and 5-10% in P_{max}.

SPECTRAL RESPONSE

The spectral response measurements are taken using a chopped monochromatic light beam as an excitation source. Cell output goes to a lock-in amplifier tuned to the light chopper frequency. This permits flooding the solar cell under test with a dc light level to check for injection level effects. (Standard space quality cells do not normally show injection level effects either before or after electron irradiation).

Figures 4 and 5 show the spectral responses of cells 20-2 and 38-1 as a function of radiation fluence. Both cells also exhibit a bandwide injection dependence which, although not shown, nearly disappears after exposure to fluences greater than 1×10^{14} e/cm^2. Figure 6 shows the spectral response of cell 34-1. Its injection dependence is remarkably strong and remains important until fluences of nearly 10^{16} e/cm^2 have been reached. All curves shown in figure 6 would be shifted upward but by a decreasing amount as the fluence increases. It appears then quite probable that these cells have large concentrations of trapping levels.

Figures 4-6 show that as radiation fluence is increased, spectral response is diminished all across the band, but most importantly they exhibit complete loss in the blue end of the spectrum after fluences of only 10^{14} e/cm^2. This contrasts strongly with the behavior of standard cells where the loss occurs only in the red end of the spectrum and the blue response remains unchanged.

CONCLUSIONS

While it is usually dangerous to draw far-reaching conclusions based on so small a sample size, certain general statements can reasonably be made concerning the cells we have studied.

1. Although these cells are attractive for their possible ease in panel assembly, they are not yet suitably developed for use in a radiation environment.

2. Varying but strong concentrations of trapping levels appear to be introduced in these cells.

3. TI has shown that the presence of the front junction is necessary for the high initial performance of these cells. The mechanism introduced by the junction must act to force either majority or minority carriers toward the rear surface of the cell for collection by the rear junction. Whatever the force is, it is readily destroyed by relatively low electron fluences. One possible mechanism for producing such a force is the existence of charged surface states on the front surface. These surface states are highly affected by 1 MeV electron irradiation and will probably be affected by electrons having energy below the displacement threshold. The surface state hypothesis may easily be tested by irradiation with electrons having energies below 100 keV.

4. Following initial loss of the force mechanism, the cells exhibit a more gradual loss in spectral response (primarily blue) which is consistent with a decreasing diffusion length and loss in the ability of carriers to traverse the thickness of the cell.

REFERENCES

1. Chiang, S., Carbajal, B. G., and Wakefield, G.F.: Thin Tandem Junction Solar Cell. Thirteenth IEEE Photovoltaic Specialists Conference, June 1978, p. 1290.

FIGURE 1. I_{SC} VS 1 MeV ELECTRON FLUENCE FOR TANDEM JUNCTION SOLAR CELLS (AMO, 28°C)

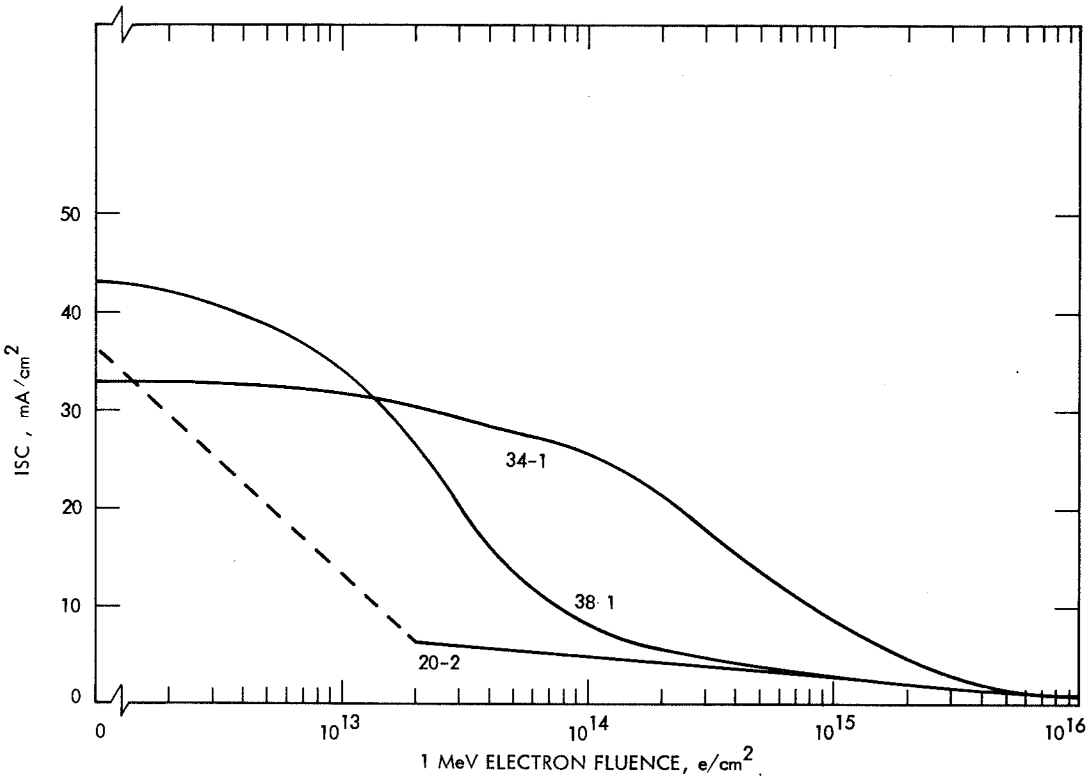

FIGURE 2. V_{OC} VS 1 MeV ELECTRON FLUENCE FOR TANDEM JUNCTION SOLAR CELLS (AMO, 28°C)

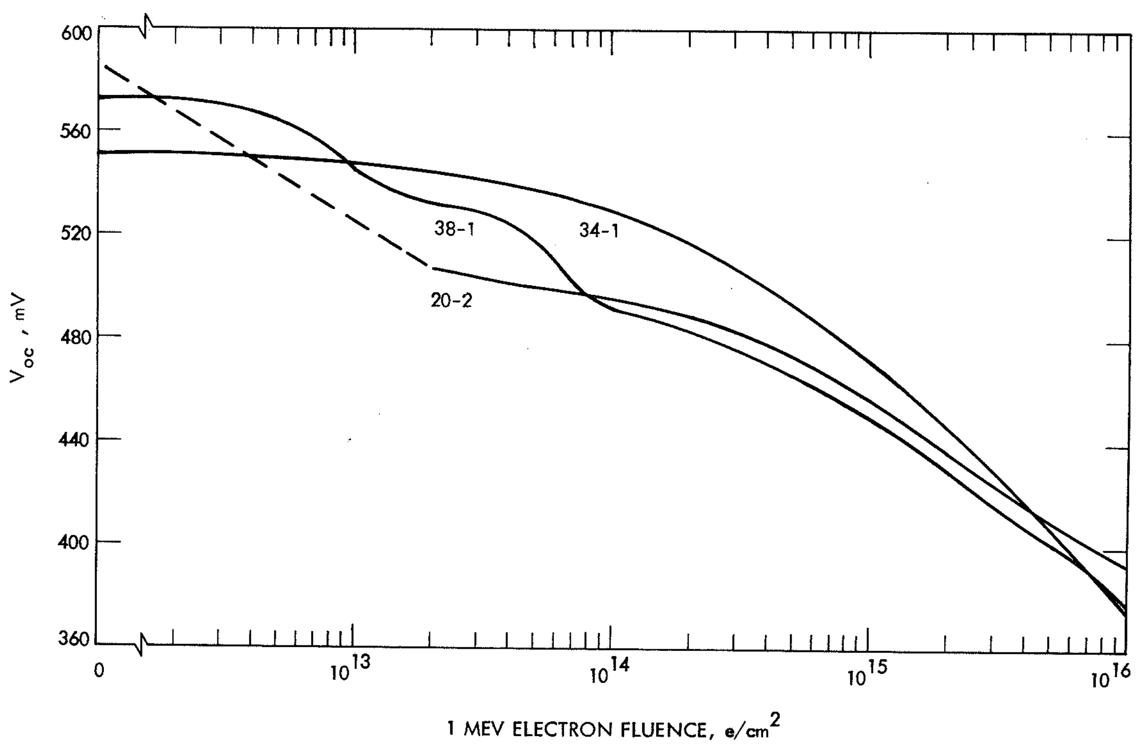

FIGURE 3. P_{MAX} VS 1 MeV ELECTRON FLUENCE FOR TANDEM JUNCTION SOLAR CELLS (AMO, 28 °C)

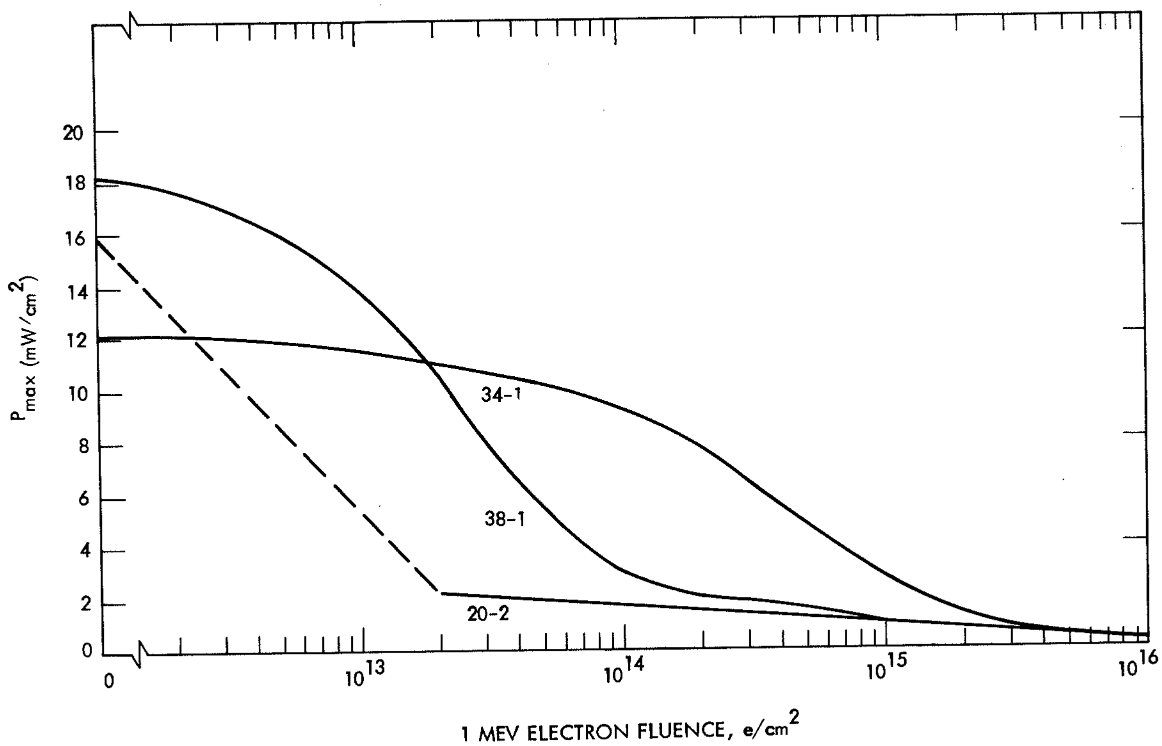

FIGURE 4. SPECTRAL RESPONSE OF CELL 20-2

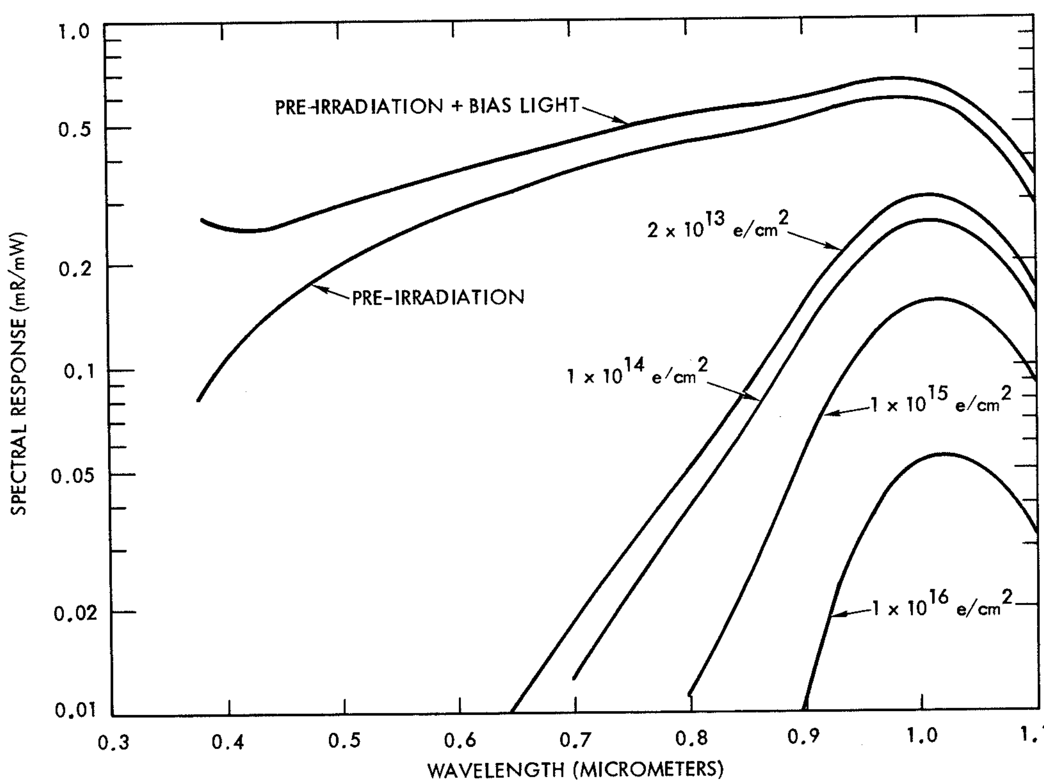

FIGURE 5. SPECTRAL RESPONSE OF CELL 38-1

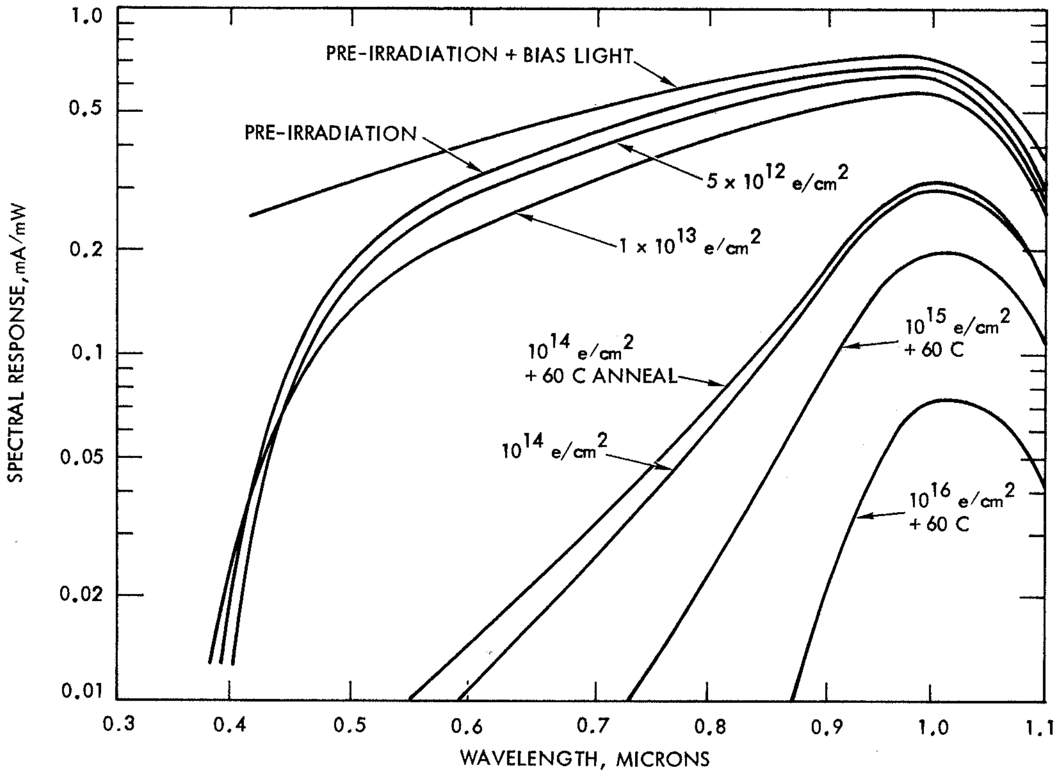

FIGURE 6. SPECTRAL RESPONSE OF CELL 34-1